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ON HANGING,

CONSIDERED FROM

A MECHANICAL AND PHYSIOLOGICAL POINT OF VIEW.

BY

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HANGING, as a mode of public execution of criminals, must be regarded as to a great extent an Anglo-Saxon mode of execution; and although occasionally practised by the nations of antiquity, it seems among them to have been used chiefly by suicides, or in cases in which especial ignominy was intended to be attached to the criminal.

Among the Hebrews, the national punishment was unquestionably that of stoning to death by stones thrown with the hand; and it is clear, from many passages in the Old Testa-

ment, that the hanging so often spoken of was the exposure of the body of the criminal, after death, to the birds of the air and to the beasts of the field, either by suspension from a tree, or by crucifixion on a gallows.

In Deut. xxi. 22, 23, it is provided that the criminal already executed shall be lifted up on a tree, and that his body shall be taken down before nightfall; it is also proved, by the story of the Hebrew thief in Herodotus, that the Jews, even before they left Egypt, had a special horror of the exposure of the dead at night to the birds of prey; for he relates that the King of Egypt exposed on a cross the headless body of the thief caught in the trap laid in the treasure-house, in the hope that his relations might be induced to attempt the removal of the body before nightfall.

From Gen. xl. 19, we may infer that the Egyptian practice was to execute the criminal by decapitation, and afterwards expose the body nailed on a cross to the birds of prey.

Among the Persians, also, exposure on a cross was a customary punishment, as appears from Esther vii. 9; but I do not know whether this crucifixion was post mortem or not; among the Hebrews, the "suspension" or "crucifixion" was always that of the dead body, and they were not guilty of the terrible atrocity of suspending or nailing up by the hands a living man: this refinement of cruelty was reserved for the Romans.

I have not succeeded in finding a case of execution by hanging in the Old Testament, although there are cases of suicidal strangulation (as that of Ahithophel, 2 Sam. xvii. 23), which may have been effected simply by tying a cord round the neck, and have been unaccompanied by any "suspension," in the Anglo-Saxon use of the term.

The most ancient account of a formal execution by hanging that I can find is the hanging of the twelve faithless handmaids of Penelope at the suggestion of Telemachus, in the twenty-second book of the Odyssey. The passage is so remarkable for many reasons, that no apology is needed for offering some suggestions respecting it. I give the translation of Cowper, for the benefit of English readers.

" leading forth
The women next, they shut them close between
The lofty wall and scullery, narrow, straight,
And dreadful, whence no prisoner might escape.
Then, prudent, thus Telemachus advised:
 The death of honour would I never grant
To criminals like these, who poured contempt
On mine and on my mother's head, and lay
By night enfolded in the suitors' arms.

He said, and noosing a strong galley rope
To a huge column, led the cord around
The spacious dome, suspended so aloft,
That none with quivering feet might reach the floor.
As when a flight of doves entering the copse,
Or broad-winged thrushes, strike against the net
Within; ill rest, entangled, there they find;
So they, suspended by the neck, expired
All in one line together. Death abhorred!
With restless feet awhile they beat the air,
Then ceased."

Ὣς ἄρ' ἔφη, καὶ πεῖσμα νεὸς κυανοπρώροιο
κίονος ἐξάψας μεγάλης περίβαλλε θόλοιο,
ὑψόσ' ἐπεντανύσας, μήτις ποσὶν οὖδας ἵκοιτο.
ὡς δ' ὅταν ἢ κίχλαι τανυσίπτεροι ἠὲ πέλειαι,
ἕρκει ἐνιπλήξωσι, τόθ' ἑστήκει ἐνὶ θάμνῳ
αὐλιν ἐσιέμεναι, στυγερὸς δ' ὑποδέξατο κοῖτος,
ὣς αἵγ' ἑξείης κεφαλὰς ἔχον, ἀμφὶ δὲ πάσαις
δειρῇσι βρόχοι ἦσαν, ὅπως οἰκτιστα θάνοιεν·
ἤσπαιρον δὲ πόδεσσι μίνυνθά περ, οὔτι μάλα δήν.
Od. xxii. 465–473.

There are two ways in which we may conceive the execution to have been effected.

1. Telemachus, with the aid of Eumæus and Philœtius, having fastened one end of the rope to one of the main pillars of the hall, made slipknots (*βρόχοι*) upon it, which were placed round the necks of the twelve women, and having passed the other, or free end of the rope, round the top of the vaulted kitchen, they then all pulled together, in sailor fashion, on the rope, and hoisted the women into the air, so as to form a funicular polygon, in which some of them necessarily hung nearer to the ground than others—*μήτις ποσὶν οὖδας ἵκοιτο.*

2. The ship-rope, with one end fastened to the pillar, was carried round the vaulted dome of the kitchen (*περίβαλλε θόλοιο*) and made fast upon itself; from this rope were then suspended smaller ropes with slipknots or nooses (*βρόχοι*), which were passed round the necks of the women, who must have been lifted up one by one for the purpose, so as to swing clear of the ground. The simile of fieldfares* and wood-pigeons caught in

* It is a very remarkable confirmation of the minute accuracy with which Homer describes every phenomenon of nature, that fieldfares (*Turdus pilaris*) are now commonly caught by falconers as food for their hawks by a contrivance almost identical with that here described. A stick or rope is placed in front of either a hawthorn, or mountain ash, covered with berries, and from it are suspended running nooses at equal intervals. The

nooses hanging from a rope stretched from tree to tree, and placed in the passage to their roost, seems rather to favour the second interpretation, which is also aided by the words ὡς αἴγ' ἐξείης κεφαλὰς ἔχον, as if the women hung, like Bluebeard's wives, "tit tat toe, all in a row!"

It can be shown, from mechanical considerations, that the first interpretation of this remarkable passage is not admissible; for, on the most favourable arrangement of the rope allowable, it would not have been possible for Telemachus, Eumæus, and Philœtius, even if aided by the "man that bent the bow," and by the willing Euryclea, to have exerted the force necessary to lift all the women into the air together. The mechanical problem is also worth investigating for its own sake.

I shall assume, in order to simplify the conditions, that the women are hung at equal distances along the rope, and that the part of the rope joining the two lowest women is horizontal. These suppositions are very natural, and have the advantage of rendering the solution more elegant, without interfering seriously with its generality.

Let $\alpha_1, \alpha_2, \ldots \alpha_6$ denote the angles made by the several portions of the rope (reckoned from the top) with the horizon.

Let $T_1, T_2, \ldots T_6$ denote the strain on each portion of the rope.

Let $T_7 = X$ be the strain on the lowest or horizontal portion of the rope.

Let W denote the weight of one of the women.

As the second half of the rope is supposed to be symmetrical for the present, there are thirteen unknown quantities to be found, viz. the six angles and seven tensions. From the well-known principles of equilibrium of the funicular polygon, we obtain the following twelve equations, which are all *mechanical*:—

$$T_1 \cos \alpha_1 = T_2 \cos \alpha_2, \quad \ldots\ldots\ldots \quad (1)$$

$$T_2 \cos \alpha_2 = T_3 \cos \alpha_3, \quad \ldots\ldots\ldots \quad (2)$$

$$T_3 \cos \alpha_3 = T_4 \cos \alpha_4, \quad \ldots\ldots\ldots \quad (3)$$

$$T_4 \cos \alpha_4 = T_5 \cos \alpha_5, \quad \ldots\ldots\ldots \quad (4)$$

$$T_5 \cos \alpha_5 = T_6 \cos \alpha_6, \quad \ldots\ldots\ldots \quad (5)$$

$$T_6 \cos \alpha_6 = T_7 = X. \quad \ldots\ldots\ldots \quad (6)$$

fieldfares (κίχλαι ταννσίπτεροι), in trying to fly at the berries, are stopped by their broad wings in passing through the nooses, and are so caught by the neck, or occasionally by the foot, but most frequently by the neck; and the stratagem is so successful with this bird, that they are often found hanging in a row from the stick, each suspended by the noose that passes round his neck.

$$T_1 \sin \alpha_1 = T_2 \sin \alpha_2 + W, \quad . \quad . \quad . \quad (7)$$
$$T_2 \sin \alpha_2 = T_3 \sin \alpha_3 + W, \quad . \quad . \quad . \quad (8)$$
$$T_3 \sin \alpha_3 = T_4 \sin \alpha_4 + W, \quad . \quad . \quad . \quad (9)$$
$$T_4 \sin \alpha_4 = T_5 \sin \alpha_5 + W, \quad . \quad . \quad . \quad (10)$$
$$T_5 \sin \alpha_5 = T_6 \sin \alpha_6 + W, \quad . \quad . \quad . \quad (11)$$
$$T_6 \sin \alpha_6 = \left\{ \begin{matrix} T_7 \sin \alpha_7 \\ = 0 \end{matrix} \right\} + W. \quad . \quad . \quad . \quad (12)$$

The twelve unknown quantities in these equations, which denote the inclinations and tensions of the first six portions of the rope, may be all expressed as follows, after a few reductions, in terms of X, the horizontal strain on the funicular polygon :—

$$\left.\begin{aligned} T_1 &= \sqrt{36W^2 + X^2}, & \tan \alpha_1 &= \frac{6W}{X}, \\ T_2 &= \sqrt{25W^2 + X^2}, & \tan \alpha_2 &= \frac{5W}{X}, \\ T_3 &= \sqrt{16W^2 + X^2}, & \tan \alpha_3 &= \frac{4W}{X}, \\ T_4 &= \sqrt{9W^2 + X^2}, & \tan \alpha_4 &= \frac{3W}{X}, \\ T_5 &= \sqrt{4W^2 + X^2}, & \tan \alpha_5 &= \frac{2W}{X}, \\ T_6 &= \sqrt{W^2 + X^2}, & \tan \alpha_6 &= \frac{W}{X}. \end{aligned}\right\} \quad . \quad . \quad (13)$$

If a_1, a_2, a_3, a_4, a_5, a_6 denote the lengths of the six portions of the rope, we obtain, from *geometrical* considerations, the following equation :—

$$\left.\begin{aligned} a_1 \cos \alpha_1 + a_2 \cos \alpha_2 + a_3 \cos \alpha_3 + a_4 \cos \alpha_4 + a_5 \cos \alpha_5 \\ + a_6 \cos \alpha_6 = \text{const.}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \end{aligned}\right\} \quad . \quad (14)$$

in which equation the constant depends on the span of the polygon from the pillar of the hall to the top of the vaulted kitchen.

If we were to substitute in equation (14) the values of the cosines of the angles found from (13), it would become an equation ultimately of a high degree, the real root of which would give the solution of the problem sought; but it is not necessary to trouble ourselves with this equation, as we know that the value of X must be real and positive, and by (13) we have

$$T_1 = \sqrt{(6W)^2 + X^2}.$$

In this equation T_1 denotes the pull on the rope that Telema-

ehus and his assistants must have used in order to hold up the free end of the funicular polygon; and since X is real, the value of T_1 will always be greater than the weight of six of the handmaids, and will be considerably greater, unless the heights of the points of suspension be very great compared with the span of the polygon. We are therefore forced to the conclusion that the hanging of Penelope's handmaids in a funicular polygon was mechanically impossible, unless pulley-blocks or some other contrivanees were employed, which are not mentioned in the text. We must therefore suppose that in this, the earliest execution by hanging on record, the rope was passed around the vaulted dome, and that separate nooses suspended from this rope were attached to the necks of the women.

In modern times hanging was a favourite mode of execution among the Anglo-Saxons; and I am indebted to Dr. Ingram, Professor of English Literature in the University of Dublin, and to J. E. Walshe, Q.C., for the following brief notice of its history in connexion with England, which will serve as a suitable introduction to my proposal for its improvement and perfection, founded on mechanical and physiological principles.

Hanging was only one of the capital punishments in use among our ancestors—women being often burned for offenees for which men were hanged, and both were burned for holding heretical opinions. Marrying a Jew or committing sodomy was at one time punishable by burying both parties alive; and beheading with an axe was, and theoretically still is, allowable in some cases. The punishment for high treason, and at one time extended to certain eases of murder, was the elaborate and brutal process of hanging, drawing, and quartering.

In "Beowulf," which Kemble believed to be a modernized form of a poem which the invaders of Britain had brought with them from their continental homes, the gallows (*galga*) figures as an old-established institution of the Teutonic races of Northern Europe.

It is mentioned by Blackstone as a somewhat singular fact, that the only warrant the sheriff has for a capital execution is the signature of the judge to the calendar, or list of all the prisoners' names, with their respective judgments in the margin.

"As for a capital felony, it is written opposite to the prisoner's name 'hanged by the neck,' formerly in the days of Latin and abbreviation 'sus. per col.' for 'suspendatur per collum.'"

Originally there was a formal precept to the sheriff under the hand and seal of the judge; but the form of it is not given in the law books, nor is it certain how long the formula now employed in sentencing a criminal ("hanged by the neck till you are dead") has been employed.

"It is clear," says Blackstone, "that if upon judgment to be hanged by the neck till he is dead the criminal be not thoroughly killed, but revives, the sheriff must hang him again." But, strangely enough, we find in the 'Vision of Piers Plowman,' a passage which seems to show that the opposite of this either was, or was believed to be, the established rule in his time:—

> "It is noght used on Earthe
> To hangen a felon
> Ofter than ones,
> Though he were a tretour."

From some cause or other, not easy to explain, it has been the custom to use a longer drop in Ireland than in England or Scotland; and there can be no doubt that it is a more humane mode of execution than the English, and also more instructive as a solemn warning to the spectators, whose feelings are not likely to be enlisted on the side of the criminal by witnessing his convulsive struggles, which are an unnecessary accompaniment of death by hanging if properly conducted. On a recent occasion in the north of England, the criminal had undergone tracheotomy some years previous to his execution; and such was the ignorance of those who conducted the hanging, that he was dropped through a short height quite insufficient to injure the spinal cord, and breathed with ease through the aperture in the trachea, suffering horrible tortures, until relieved by the humanity of the surgeon of the jail, who closed with his finger the aperture through which he breathed, and so completed the clumsy work of the hangman.

In using the long drop, also, mistakes may occur, either through the weakness of the rope, or through miscalculation of the length of the drop. Both these errors were exemplified at Castlebar in Ireland in 1786, at the execution of the notorious George Robert Fitzgerald, who, when he jumped off the ladder, broke the rope; and when he was hanged the second time the rope was too long and his toes touched the ground, until at length a humane bystander raised him up while the hangman shortened the cord.

Death is produced by hanging in one or other of the three following ways:—

1. By apoplexy, caused by pressure on the jugular veins;
2. By asphyxia, caused by stoppage of the windpipe;
3. By shock of the medulla oblongata, caused by fracture of the vertebral column.

In the first two cases death is preceded by convulsions, lasting from five to forty-five minutes, which are caused by the cessation of the supply of arterial blood to the muscles. In the third case death is instantaneous and painless, and is unaccompanied by any convulsive movement whatever.

According to the original form of death-punishment for treason in England, the hanging was used as an anæsthetic, preparatory to the disembowelling (or drawing) that always preceded the quartering of the criminal; and the present slow process of hanging practised by Calcraft and others in England and Scotland, which consists in dropping the patient through three or four feet and allowing him to hang until dead, is the faithful representation of the original process of hanging, which was intended to fulfil a purpose quite distinct from that of speedy execution of the criminal.

It seems to me unworthy of the present state of science to continue a mode of execution which, as at present used, is extremely clumsy and also painful to the criminal. Instead of the "short drop" generally used, we ought to employ the "long drop," which causes instantaneous death. It has been ascertained by me that the shock of a ton dropped through one foot is just sufficient to fracture the anterior articulating surfaces of the second vertebra at their contact with the atlas; and that this fracture allows the shock to fall upon the medulla oblongata so as to produce instantaneous death. As the result of some consideration bestowed upon this subject, I would recommend the adoption of the following rule:—

Rule I. "Divide the weight of the patient in pounds into 2240, and the quotient will give the length of the long drop in feet."

For example, a criminal weighing 160 lbs. should be allowed 14 feet drop. If local circumstances will not allow of the long drop being employed, the requisite shock should be produced by strapping a shot to the feet, so as to secure the shock of 2240 foot-pounds to the medulla.

Efforts have been made in the United States to give to hanging all the rapidity of death by the guillotine without the painful spectacle of bloodshed. This method, which is borrowed from the mode of execution practised on board ship, consists in suddenly lifting the criminal into the air by means of a great weight attached to the other end of the rope fastened round his neck; the rope passes over a pulley placed vertically over the patient, and at a given signal the weight falls through a regulated height, lifting him suddenly into the air. Sufficient attention, however, has not been paid, even in that enlightened country, to the conditions necessary to be fulfilled in this mode of suspension; for in many of their executions, the only care that seems to have been taken was to make the falling weight heavier than the criminal, so as to ensure his permanent suspension by the neck until death terminated his sufferings.

The American method of hanging, if properly applied, seems

to me to be capable of producing death by shock with even less suffering than the "long drop;" for although by the latter method death is instantaneous when the shock actually occurs, yet the mental sufferings of the criminal during the second occupied by his fall may be very considerable. This painful interval is altogether avoided in the American method, provided the *initial* shock be sufficient to destroy the medulla oblongata. This important condition may be effected by the following calculations, which lead to an easy Rule.

The falling weight, acting through the intervention of the rope, produces its effect in a manner similar to that of the shock or collision of imperfectly elastic bodies.

Let m and m' denote the masses of the two bodies, and let v and v' denote their velocities previous to collision or shock, while e denotes the coefficient of elasticity of the rope.

Let u, u' denote the velocities of the masses m, m' after the shock; then it is well known* that

$$\left.\begin{aligned} u &= \frac{mv + m'v' - em'(v - v')}{m + m'}, \\ u' &= \frac{mv + m'v' - em(v' - v)}{m + m'}. \end{aligned}\right\} \quad . \quad . \quad . \quad (15)$$

The *vis viva* lost during the shock is expended upon the neck of the criminal, and is represented by

$$mv^2 + m'v'^2 - mu^2 - m'u'^2.$$

After some reductions this is found to be

$$\textit{vis viva} \text{ lost} = \frac{mm'}{m + m'}(1 - e^2)(v - v')^2. \quad . \quad . \quad (16)$$

This result may be applied practically to the solution of the American problem of hanging, so as to cause instantaneous death, in the following manner.

Let P denote the weight employed, and Q the weight of the criminal; let e denote the coefficient of elasticity of the rope used, and v the velocity acquired by the weight Q in falling through the height h.

If we consider the problem of the weight Q moving with the velocity v, and causing the weight P to move through the intervention of the rope whose elasticity is e, the shock produced on P at the moment when the "chuck" takes place is similar to that which occurs in the collision of bodies striking each other, and is measured by the *vis viva* lost during their collision. The

* *Vide* 'Manual of Mechanics,' p. 156.

vis viva lost during the shock is (16)

$$\frac{1}{g}\cdot\frac{PQ}{P+Q}(1-e^2)v^2;$$

but since the *work lost* is half the *vis viva lost*, if we substitute for v^2 its value, $2gh$, we find

$$\text{work lost} = \frac{PQ}{P+Q}(1-e^2)h. \quad . \quad . \quad . \quad . \quad (17)$$

For the ropes usually employed, e may be regarded as a very small fraction, and e^2 may be totally disregarded. The *work lost* is expended in causing shock to the neck, and should therefore be equal to at least 2240 foot-pounds.

In a case of hanging that came under my own observation, the criminal weighed 160 lbs., and was allowed to fall through 14 feet 6 inches, which, allowing for some elasticity in the rope, would correspond with 2240 foot-pounds of shock; in this case the superior articulating surfaces of the second vertebra were fractured near their posterior border (the fracture of the bone extending to the foramina for the vertebral arteries), but the odontoid process and its transverse ligament were so strong that neither of them was injured. Death in this case was as instantaneous as it would have been had the transverse ligament given way instead of the bone; for the shock reached the medulla, and its consequence was immediate and painless death. In hanging, the rope supports the atlas and presses it against the occipital articulations, while the second vertebra tends to fall with the body; and it follows from this, that either the odontoid process and its transverse ligament must give way, or the second vertebra be broken across at its superior articulating surfaces; in either case death will be immediate. The height of the criminal just mentioned a few days before execution was 5 feet 9½ inches, and after death he was found to measure 5 feet 11 inches; having been elongated by 1½ inch by the "long drop" of 14½ feet.

From the foregoing it therefore appears that a shock to the neck of 2240 foot-pounds is just sufficient to cause immediate death; substituting, therefore, 2240 foot-pounds for the work lost in the preceding equation, we find

$$2240 = \frac{PQh}{P+Q},$$

or, solving for P,

$$P = \frac{2240Q}{Qh-2240}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)$$

From this equation it follows that, unless Qh be greater than

2240, the value of P (the weight required) will be negative; but Qh denotes the work produced by the criminal Q falling through the height h.

Let h therefore denote the "long drop" found by Rule I., and the following consequences may be inferred from (18).

1st. In the American mode of hanging, if the weight be let fall through the height h, sufficient to cause death instantaneously by the "long drop," it would require an infinite weight to cause immediate death; for in this case

$$Qh - 2240 = 0,$$

and therefore P is infinite.

2nd. In the American mode of hanging, if the weight be let fall through twice the height of the "long drop," a weight equal to that of the criminal will be sufficient to cause immediate death; for in this case

$$Qh - 2240 = 2240,$$

and therefore, by equation (18),

$$P = Q.$$

For all heights intermediate between h and $2h$, the weight P must be found from equation (18), and it will always lie between Q and infinity.

In practice, twice the height of the "long drop" would always be found convenient; and therefore the following Rule for producing instantaneous death by the American method is confidently recommended.

Rule II. "Having found from Rule I. the height of the Irish long drop, use twice this height, and a weight equal to that of the criminal, in the American method.

Note.—I have searched in vain for well-authenticated instances of fracture of the cervical vertebræ produced by the usual method of hanging. Among the longest drops that I can find recorded, are two observed by Dr. Charles Croker King, when Professor of Anatomy in the Queen's College, Galway.

Case I.* A young man, named Hurley, was executed in Galway, at 6.25 P.M. on the 27th of August, 1853, for the murder of a young woman in Dunsandle Wood. The rope used was 10 lines in diameter; the knot was large, formed of three turns of the rope, and, on the noose being tightened by the executioner, corresponded to the occipital protuberance. His weight was $10\frac{1}{2}$ stone, and he was allowed a drop of $7\frac{1}{2}$ feet. These data give us as follows:—

$$\text{work done} = 147 \times \frac{15}{2} = 1102 \text{ foot-pounds.}$$

* Dublin Quarterly Journal of Medical Science, vol. xviii. (1854) p. 86 *et seq.*

In this case, as Dr. King remarks, "there was no dislocation or fracture of the vertebral column, or injury of the ligaments or of the spinal cord."

Case II.* On the 11th of May, 1858, Patrick Lydon was hanged in Galway for the murder of his wife. Lydon was a small man, only 5 feet 5 inches in height; the diameter of the rope was 10 lines; his weight was $9\frac{1}{2}$ stone, and the drop 11 feet. Hence we find

$$\text{work done} = 133 \times 11 = 1463 \text{ foot-pounds.}$$

In this case, "that portion of the anterior common ligament of the spine which passes from the body of the second to that of the third cervical vertebra was ruptured, so that the left halves of the bodies of the above-mentioned vertebræ were separated from each other by an interval of one-eighth of an inch, but there was no displacement."

These criminals were executed with the same rope, and death in the second case was not preceded by violent muscular convulsions, as in the first case—a fact which is readily accounted for by the excess of shock in the proportion of 1463 to 1102.

* Dublin Quarterly Journal of Medical Science, August 1863.